11 May 2009

Implicated Effects of Water on Electron Drift Lifetime in Liquid Argon

Introduction

Liquid argon time projection chambers (LArTPCs) offer an opportunity for novel neutrino physics (1). They function by drifting ionization electrons created by particle tracks to readout planes composed of thin wires. A principal challenge for large LArTPCs is the removal of electronegative impurities that attach to ionization electrons and prevent their detection. The Material Test System (MTS) has been created at FNAL to develop liquid argon purification techniques (2) and characterize electronegative impurities used in the construction of a large LArTPC. A schematic of the MTS is included below as Figure 1.

Some of the features of the MTS relevant to this note are the following.

- *Scrubber filter.* This filter actively filters liquid argon using a combination of zeolite (3) and activated copper (4) and essentially no moving parts. It can be used to maintain the purity of the argon in the cryostat and also to remove impurities that may be introduced during materials testing. A description of filter operation can be found in (2).
- *Purity monitor.* Modeled after the purity monitors of the ICARUS Collaboration (5), this apparatus allows for the direct measurement of the electron drift lifetime, the relevant representation of electronegative impurites for liquid argon time projection chambers. A brief discussion of the electron drift lifetime and its calculation can be found in (2).
- *Raining condenser to control cryostat pressure.* Argon vapor enters the condenser through a central tube and contacts surfaces cooled with liquid nitrogen pressurized to 35 psig. The condensed argon flows down the condenser walls and drips into one of four filters before entering the bulk liquid of the cryostat. When the condenser is not operating, argon is continuously vented. A closed system is desirable during material tests so that material-introduced impurities remain in the cryostat and their effect on electron drift lifetime can be monitored.
- *Return filter for filtering condensed argon.* Below the condenser is a set of four filters, any one of which may be placed beneath the condenser outlet to catch and filter the condensate before it enters the bulk liquid. For the purposes of this note, there was a filter of sintered metal, one of sintered glass, one consisting of a thin tube, and one consisting of a hole. Please see Fig. 3 for details.
- *Mechanisms for material insertion.* Materials may be placed into a sample cage inside the airlock, evacuated and/or purged with argon vapor from the MTS cryostat, and then lowered into the cryostat and set on a lift platform equipped with an RTD to indicate temperature. The airlock may then be closed and the material may be lowered into the bulk liquid.

Operation of the MTS involves evacuating the cryostat, filling it with filtered commercial argon, inserting a material sample, and monitoring the electron drift lifetime. Upon evaluation, the sample may be removed and another sample material inserted. The condenser and internal filter may be operated as desired or needed.

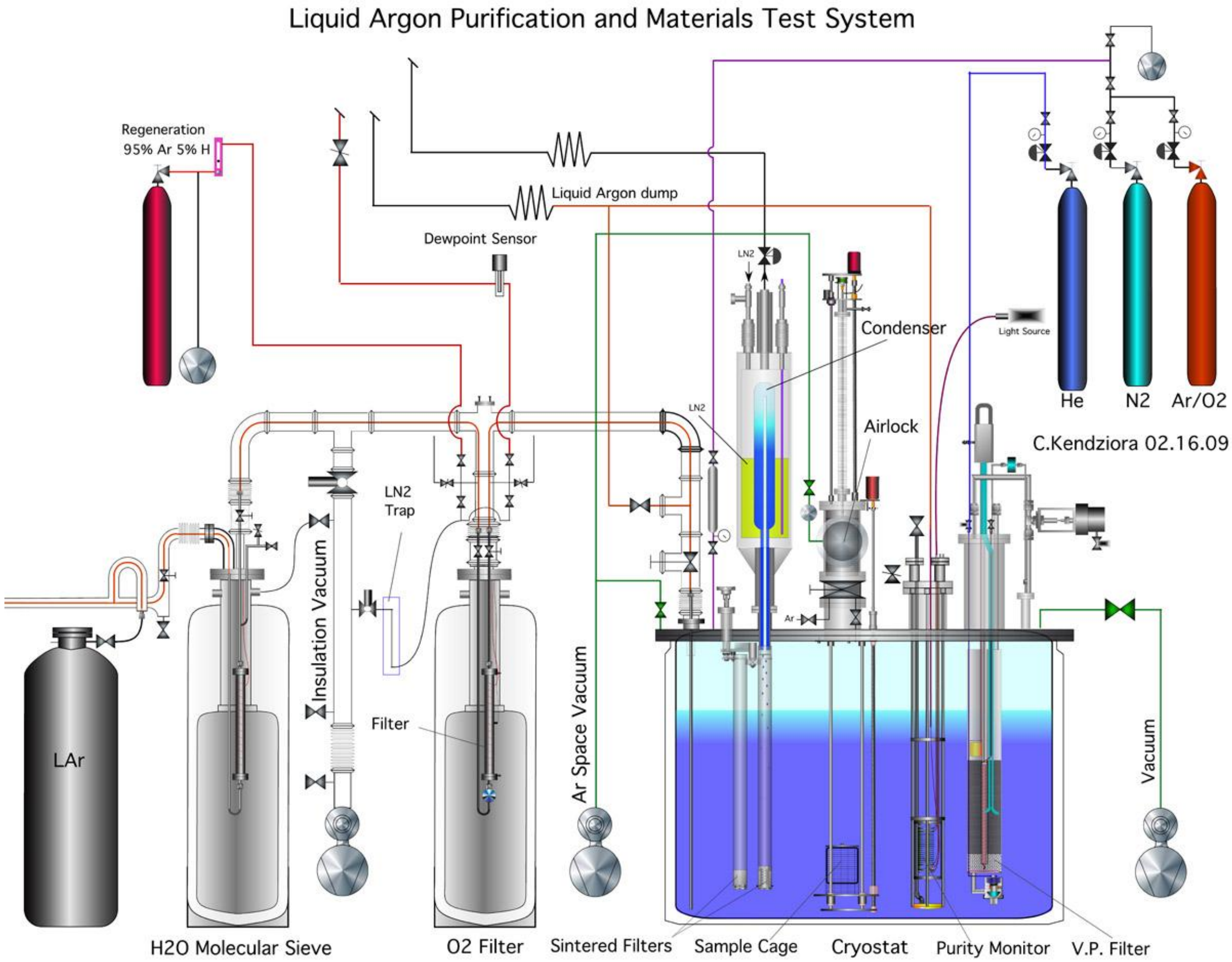

Figure 1: Schematic of the Materials Test System (MTS) at FNAL.

Effect of Condenser Operation on Electron Drift Lifetime

The condenser was first used to control MTS cryostat pressure in late 2007. Condensate was allowed to drip into the bulk liquid. It became apparent that condensing reduced the electron drift lifetime drastically. See Figure 2. In order to characterize the effect of condenser operation, a series of return filters were installed beneath the outlet of the condenser, as shown in Figure 1 and detailed in Figure 3. A return filter is selected by rotating a handwheel that extends outside the cryostat.

The media for the return filter were chosen for their ability to distinguish between possible condenser-associated impurities, initially thought to be either ions or ice/particulate. The thin, spiraled tube was designed to prevent the condensed argon from dripping into the bulk liquid. This would help prevent charge separation that results from fluid flow against a dissimilar surface (6) and prevent the generation of ions that might adversely affect the drift lifetime. The sintered glass was chosen for its ability to remove particulate, but not discharge any ions generated by dripping condensate. The sintered metal and steel wool were chosen for their ability to remove both ions and particulate. The hole provided a baseline to which to compare the effects of the other return filters.

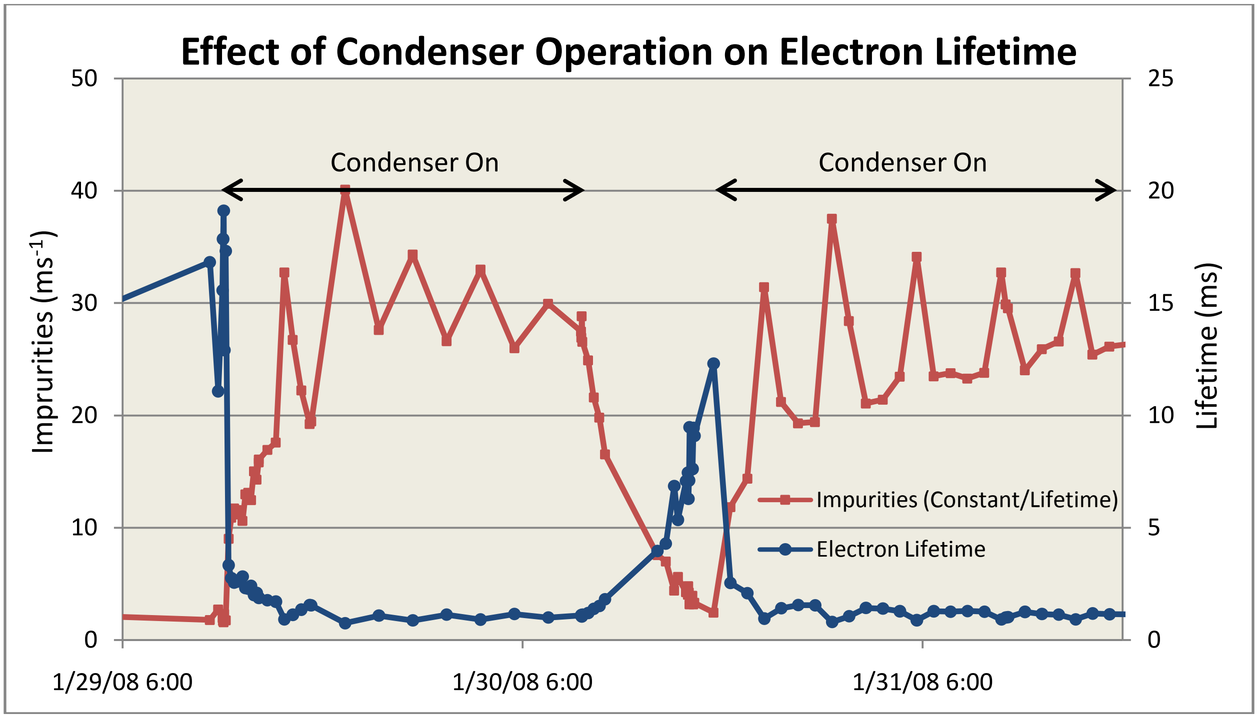

Figure 2: Effect of Condenser Operation on Electron Drift Lifetime. Imps is a quantity defined as a constant divided by the drift lifetime.

The cryostat was initially filled with 29 inches of argon, enough to cover the outlets of all the return filters except the hole. The effect of filtering the condensate through each of the returns was observed and results are shown in Fig. 4. The impurities in the cryostat were modeled assuming there was an infinite reservoir of condenser-associated impurities and that condenser operation introduced these impurities to the bulk liquid at a constant rate. Each of the return filters was allowed to reduce the rate of introduction by a constant fraction. For modeling purposes, scrubber filter operation was allowed to remove any impurities in the bulk liquid. Without active filtration, condenser-independent impurities accumulate in the bulk liquid but the condenser-associated impurities are allowed to passively exit.

Figure 4 shows the relative success of stainless steel and sintered metal as a return filter. The performance of the other returns does not conclusively support the hypothesis that condensing introduces ions or ice/particulate into the bulk liquid. A new hypothesis was formed that condenser-associated impurities are emitted from warm metal surfaces but adsorb to cold metal surfaces. Return filter performance is related to the amount of cold metal surface area presented to the condensate. This hypothesis was adopted because it accounts for the difference in return filter performance as well as the passive removal of condenser-associated impurities from the bulk liquid. As a check on this hypothesis, the amount of cold metal surface area presented by the return filters to the condensate was decreased by lowering the liquid level in the cryostat. The filters removed fewer condenser-associated impurities in this new operating condition. See Table 1.

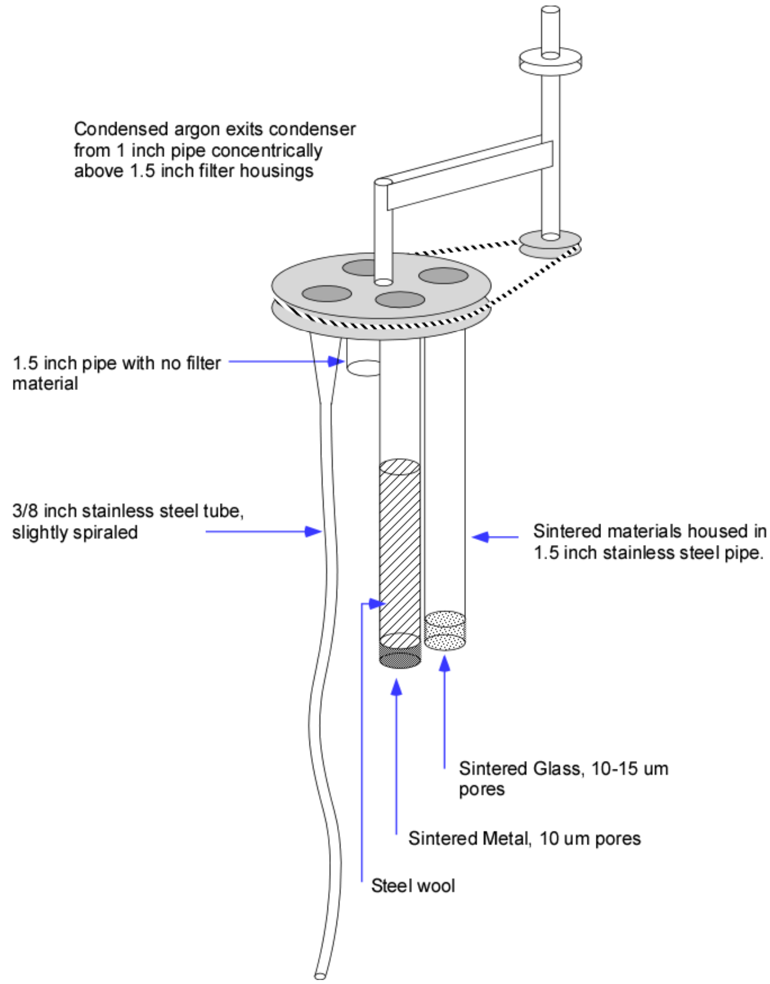

Figure 3: Detail of Return Filter Mechanism. The thin tube extends approximately 36 inches into the cryostat, which has a depth of 40 inches. The housings for the sintered metal and sintered glass extend approximately 20 inches into the cryostat.

Return Filter	**Cold Metal Surface Area Presented to Condensate**		**Electron Lifetime**	
	29 Inches LAr	*16 Inches LAr*	*29 Inches LAr*	*16 Inches LAr*
Hole	0	0	1.1	1
Thin Tube	150 cm^2	70 cm^2	1.5	1.3
Sintered Glass	300 cm^2	Near 0 cm^2	2.4	1.2
Sintered Metal	A lot	A lot	5 to 8	5 to 8
N/A (Venting)	N/A	N/A	10-20	10-20

Table 1: Electron Drift Lifetime as Related to Return Filter and Liquid Level.

Condenser-associated impurities can be actively removed with the scrubber filter, suggesting the source of these impurities is not liquid argon but the cryostat, which is evacuated before fill. Water is well known to remain on metal surfaces in vacuum (7) and may be cryopumped, making it a likely appellation for condenser-associated impurities.

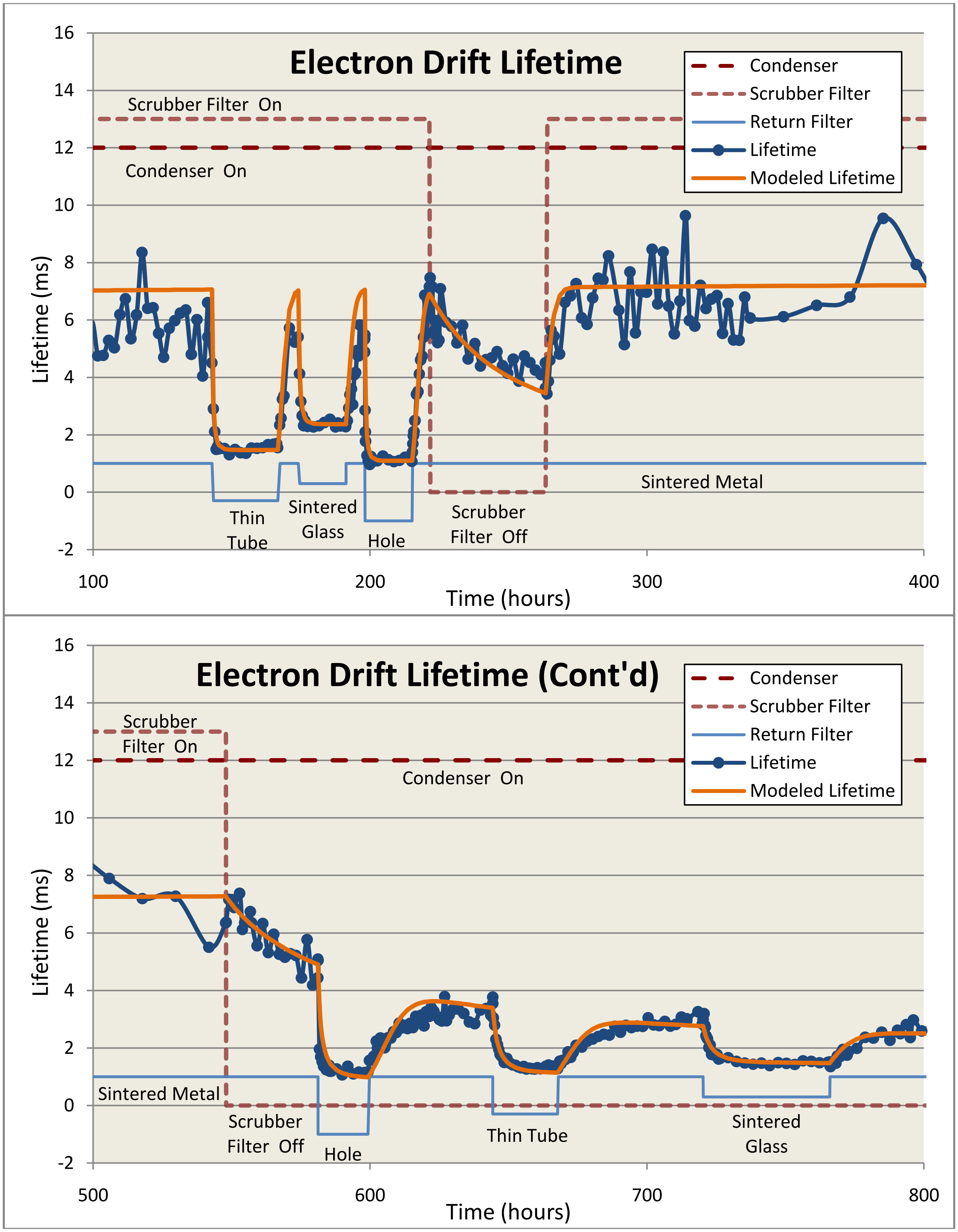

Figure 4: Electron Drift Lifetime as a Function of Condensate Filtering. The levels representing the condenser, scrubber filter, and condenser filter indicate their operational status.

Implicated Effects of Water on Electron Drift Lifetime

A Tiger Optics moisture analyzer (8) with a 2 ppb detection limit and 1 ppb resolution was used to monitor the water concentration in the MTS cryostat. The ullage was monitored for moisture content because the moisture analyzer was not sensitive to concentrations in the liquid.

The airlock volume was conjoined with that of the cryostat to help determine the effect of additional metal surface area. The scrubber filter was operation and the sintered metal was used as the condenser return. It is thought the additional metal surface area added moisture to the system and caused the electron lifetime to decrease. See Figure 5.

A series of material tests were performed to determine the effect of various printed circuit board materials on the electron lifetime. Test materials were inserted in the airlock and evacuated and purged with argon from the cryostat and then lowered into the liquid and subsequently raised into the ullage. Material tests were conducted with the scrubber filter operational and the sintered metal as the return filter. While testing of FR-4 and taconic, it was noted that the water concentration in the ullage was indicative of electron drift lifetime (see Fig. 6) in a way similar to that of conjoining the cryostat and the airlock. In both scenarios, the product of the electron lifetime and the water concentration equals a constant: with the sintered metal as the return filter, [Electron Lifetime in ms]*[H2O Concentration in ppb]=17. It was also noted that upon evacuation in the airlock (for a few days) prior to testing, PC board materials had little effect on the electron drift lifetime (see Fig. 7). These characteristics suggest water may be the sole significant electronegative impurity introduced by PC board materials and metal surfaces.

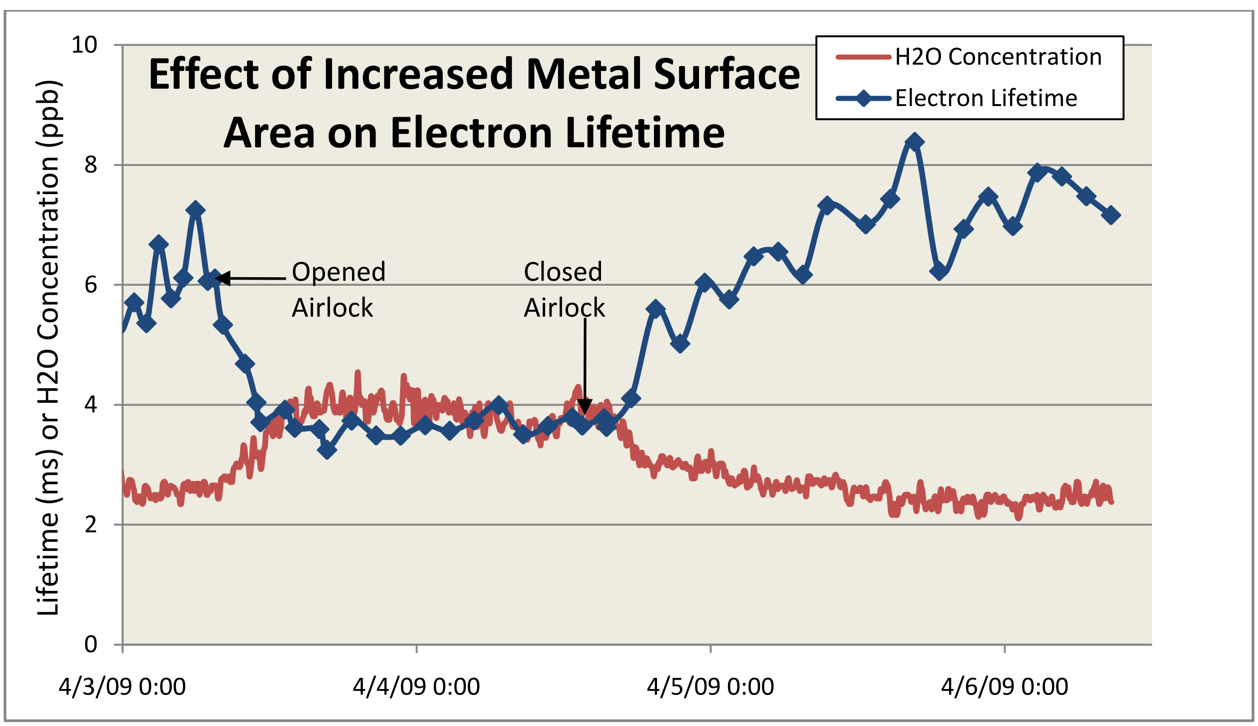

Figure 5: Effect of Conjoining Airlock and Cryostat Volumes. The material test was performed with 15 inches LAr present in the cryostat.

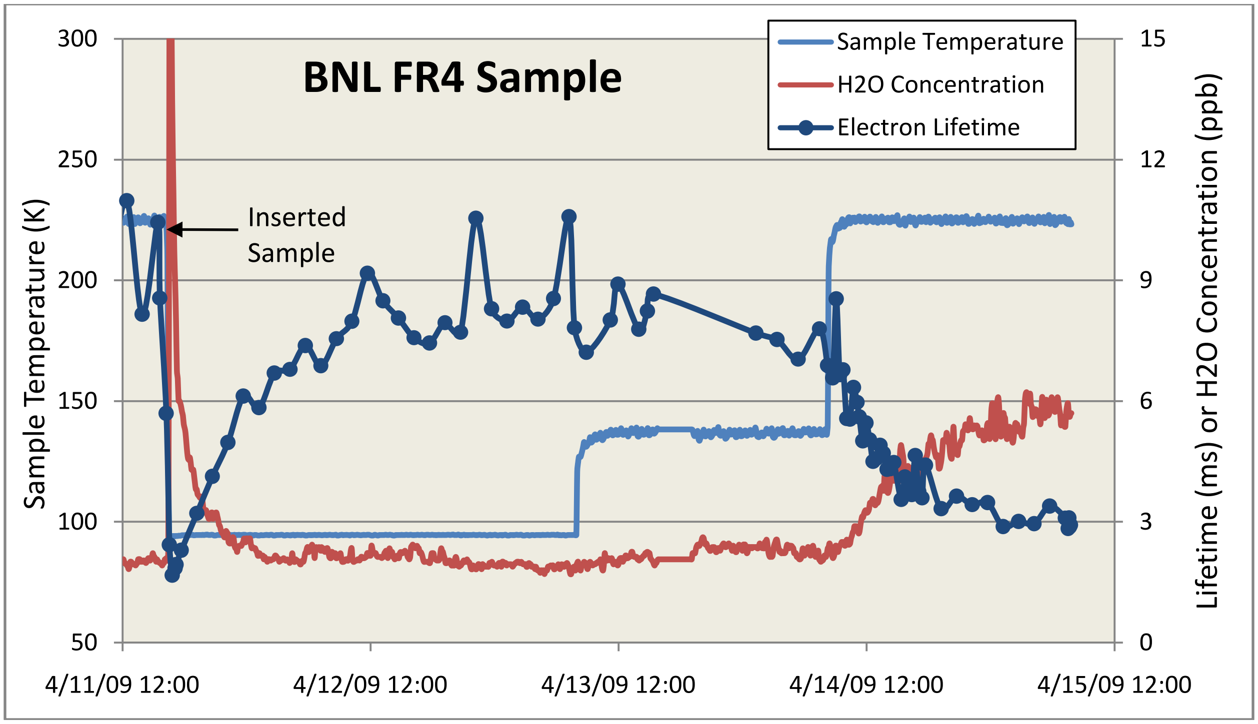

Figure 6: BNL FR4 Material Test. The sample was first lowered into the liquid argon then raised so that the temperature of the sample was increased. When moved to 225 K, the sample began to outgas and the effect on H2O concentration and electron lifetime can be seen. The material test was performed with 17 inches LAr present in the cryostat.

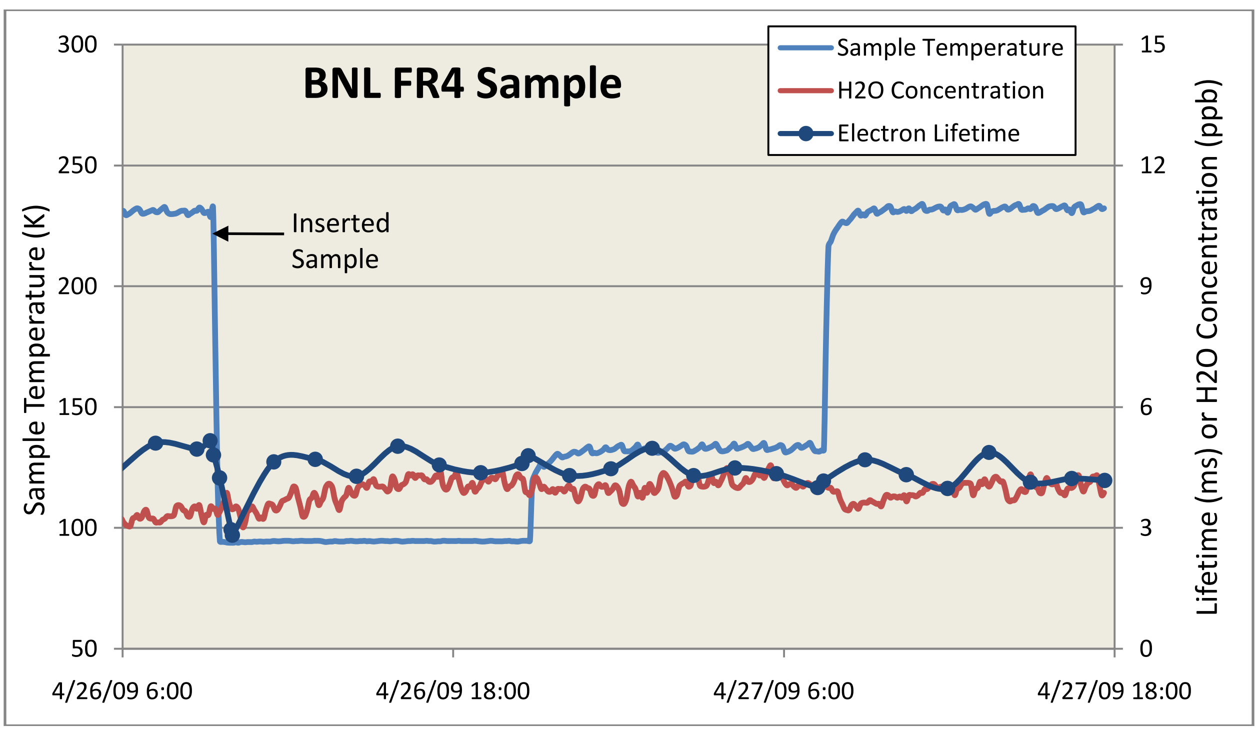

Figure 7: BNL FR4 Material Test. The BNL FR4 sample was placed in the airlock and evacuated to 1 mTorr for a few days before being lowered into the liquid. When moved to 225 K, the sample did not outgas any water and had no effect on the electron lifetime. The material test was performed with 13 inches LAr present in the cryostat.

Speculations

There are indications that small (<1 ppb) water concentrations in liquid argon greatly affect the electron drift lifetime. We have not yet established a direct relationship between the electron lifetime and the water concentration in liquid argon. Whatever the exact nature of the contaminant, it is clear that the condensate must be filtered before returning to the cryostat if long electron drift lifetimes are to be achieved.

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